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# LoCuSS: exploring the connection between local environment, star formation, and dust mass in Abell 1758

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## ABSTRACT

We explore the connection between dust and star formation, in the context of environmental effects on galaxy evolution. In particular, we exploit the susceptibility of dust to external processes to assess the influence of dense environment on star-forming galaxies. We have selected cluster Abell 1758 from the Local Cluster Substructure Survey (LoCuSS). Its complex dynamical state is an ideal test-bench to track dust removal and destruction in galaxies due to merger and accretion shocks. We present a systematic panchromatic study (from 0.15 µm with *GALEX* to 500 µm with *Herschel*) of spectroscopically confirmed star-forming cluster galaxies at intermediate redshift. We observe that the main subclusters (A1758N and A1758S) belong to two separate large-scale structures, with no overlapping galaxy members. Star-forming cluster members are found preferentially outside cluster central regions, and are not isotropically distributed. Rather, these galaxies appear being funneled towards the main subclusters along separate accretion paths. Additionally, we present the first study of dust-to-stellar (DTS) mass ratio used as an indicator for local environmental influence on galaxy evolution. Star-forming cluster members show lower mean values (32 per cent at 2.4σ) of DTS mass ratio and lower levels of infrared emission from birth clouds with respect to coeval star-forming field galaxies. This picture is consistent with the majority of star-forming cluster members infalling in isolation. Upon accretion, star formation is observed to decrease and warm dust is destroyed due to heating from the intracluster medium radiation, ram-pressure stripping, and merger shocks.

**Key words:** galaxies: clusters: individual: Abell 1758 – galaxies: evolution – galaxies: star formation.

## 1 INTRODUCTION

Dust plays an important role in shaping the evolution of galaxies. It acts as a catalyst for the formation of molecular gas, which accumulates in the dense and cold clouds that become the birthplace of stars (Galliano, Galametz & Jones 2018, for a review). Dust is also responsible for reprocessing ultraviolet (UV) radiation from newly born stars, resulting in an extinction of light from galaxies at short wavelengths, and a re-emitting of that energy at infrared wavelengths. It is thought that dust formation occurs predominantly via the growth of grains in external layers of asymptotic giant branch star atmospheres and supernovae ejecta, which are later distributed into the interstellar medium by stellar winds.

As it traces the creation of galaxy's stellar content, and is mixed through the interstellar medium, measurements of the dust content are crucial for understanding why the star formation rate (SFR) density of Universe has declined since $z \sim 2$ and what drives the quenching of star formation. Observations have shown that while star-forming galaxies have high dust content (particularly as a fraction of their stellar mass), passive galaxies do not (Smith et al. 2012). This has been extended by showing that the dust mass of a galaxy directly correlates with the SFR, at least for galaxies in the field (da Cunha et al. 2010). It is not clear what happens to the dust created during star formation, such that it is no longer detected in massive and passive galaxies. It has been proposed that it is destroyed via mechanisms internal to the galaxy, such as supernovae shocks (Jones 2004, for a review), or is driven out of the galaxy by an outflow or consumed less efficiently due to heating from active galactic nuclei (Gobat et al. 2018).

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**Table 1.** Summary of the principal properties of the two main subclusters, A1758N and S, and the X-ray group A1758-g8 from Haines et al. (2018). From left to right, halo name, central coordinate, number of spectroscopically confirmed members, X-ray luminosity $L_X$.

| Name | Centre (RA, Dec.) (RA, Dec.) | N | Redshift z | $L_X$ (0.1 2.4keV) [$10^{44}$ erg s $^{1}$] | Mass $M_{200}$ [$10^{14}$ M ] | Radius $r_{200}$ (Mpc) | Velocity dispersion (km s $^{1}$) |
|---|---|---|---|---|---|---|---|
| A1758N | 203.18848, 50.54294 | 176 | 0.27879 – 0.0064 | 7.514$^{a}$ | 18.21 – 3.59$^{c}$ | 2.77 – 0.18 | 1440 – 104 |
| A1758S | 203.13729, 50.41702 | 74 | 0.27386 – 0.00426 | 4.056$^{b}$ | 7.72 – 1.50$^{d}$ | 1.74 – 0.11 | 1020 – 78 |
| A1758-g8 | 203.04446, 50.50874 | 17 | 0.27891 – 0.00097 | 0.041$^{b}$ | 0.41 – 0.07$^{d}$ | 0.65 – 0.04 | 300 – 81 |

*Note:* [a]from *ROSAT*, [b]from *XMM Newton*, Haines et al. 2018), mass $M_{200}$, [c]from the combined *Chandra XMM* analysis of Martino et al. 2014, whereas [d]is computed using the scaling relation between X-ray luminosity $L_x$ and $M_{200}$ from Leauthaud et al. 2010), radius $r_{200}$ and velocity dispersion, which is estimated from the velocity distribution of member galaxies. $M_{200}$ is defined as the mass contained within $r_{200}$, which encompasses an overdense region presenting an average density 200 times higher than the Universe critical density at the cluster redshift $_{crit}$(z), i.e. $M_{200} = \frac{4}{3} \; r^3_{200} 200 \; _{crit}(z)$ (Voit 2005).

Even more uncertain is what role dust plays in the environmentally driven suppression, or quenching, of star formation. Environmental processes have been shown to affect atomic gas content, resulting in truncated density profiles in the outskirts of galaxies (Davis et al. 2013). Environmental effects on molecular gas, and consequently on dust, are still a subject of debate (Cortese et al. 2012; Koyama et al. 2017), but there are measurements of the spatial distribution of dust in cluster galaxies that are consistent with it having been stripped from the galaxy (Gomez et al. 2010; Walter et al. 2011). Further evidence for differential dust content in clusters and the field was found in the first systematic dust surveys of the Local Universe (Cortese et al. 2012). While this has shown that the dust content of galaxies in clusters is different from that of galaxies in the field, the physical mechanism causing this could be any of ram-pressure stripping (Gunn & Gott 1972; Jablonka et al. 2013), galaxy harassment (Moore, Katz & Lake 1996), strangulation (Larson, Tinsley & Caldwell 1980), or heating from the intracluster medium (ICM; Mok et al. 2016).

Clearly, a powerful method to test models of dust formation and destruction, and their relation to star formation, is to examine how key scaling relations, such as between dust and stellar mass and dust mass and SFR, vary in different environments. Furthermore, the cluster s dynamical state has to be taken into account. Merger events are accompanied by shock fronts, expanding through the ICM, which in turn can affect the gas and dust content in cluster galaxies.

In this paper, we concentrate on a single cluster Abell 1758 (A1758) at z = 0.28, which is known for its complex formation history forged by recent and ongoing mergers of separate clusters (Table 1 and Fig. 1). A1758 is therefore an ideal laboratory in which to study the impact of local environment within clusters and cluster dynamics on dust content in member galaxies.

X-ray analysis by David & Kempner (2004) first evidenced the absence of excess X-ray emission between A1758N and S, which originates from merger shocks compressing the ICM. This suggested that A1758N and S have yet to interact with each other. Further analysis of *Chandra* images revealed that the broadly peaked X-ray emission to the North is associated with two prominent subclumps A1758NW and A1758NE separated by 800 kpc, and currently receding from each other, being observed some 300 Myr after the first core-passage (David & Kempner 2004). Recently, Schellenberger et al. (2019) has confirmed this scenario, and additionally identified a shock front on the North side of the subcluster A1758NW, best fit by a supersonic collision with Mach number 1.6, indicating a relative velocity of 2100 km s $^{1}$. David & Kempner (2004) hypothesized that the South subcluster is further divided into two substructures, which will merge perpendicularly to the plane of the sky (Monteiro-Oliveira et al. 2017; Schellenberger et al. 2019). The scenario of multiple clumps at different stages of merging is also corroborated by numerical simulations by Durret, Laganá & Haider (2011) and Machado et al. (2015). The zoomed-in image on A1758N with *Hubble* ACS (Coe et al. 2019) confirms that the majority of cluster members present spheroidal/elliptical morphology. Nevertheless, disc galaxies emerge at increasing distance from the cluster cores. Distinct spiral arms, together with signatures of ram-pressure stripping (Ebeling & Kalita 2019), indicate that these galaxies are undergoing first encounter with the cluster environment.

This paper is structured in the following manner. In Section 2, we present the data sets used. In Section 3, we present the methods and main results of the data analysis. In Section 4, we discuss the results and future prospects of the project. Throughout this work, we assume $H_0$ = 70 km s $^{1}$Mpc $^{1}$, $_{M}$ = 0.3, and = 0.7, and will not explicitly write the base (always 10) of logarithms.

## 2 OBSERVATIONAL DATA

A1758 is among the clusters selected for the Local Cluster Substructure Survey (LoCuSS) survey (Smith et al. 2010). As a result, it benefits from the extensive coverage in both wavelength and area with *GALEX* (far-UV and near-UV), Subaru/Suprime-Cam (*g* + and *R* bands), UKIRT/WFCAM (*J* and *K* band), mid-infrared 24 µm with *Spitzer*/MIPS (reaching 90 per cent completeness at 400 µJy) and far-infrared with *Herschel* (Haines et al. 2010; Pereira et al. 2010; Smith et al. 2010), both covering 25 arcmin × 25 arcmin fields. In particular, as part of the LoCuSS Open Time Key Program on *Herschel* A1758 was observed at 100 and 160 µm with PACS and at 250, 350, and 500 µm with SPIRE (Smith et al. 2010). *Herschel* flux limits are 13.0, 17.0, 14.0, 18.9, 20.4 mJy from 100 to 500 µm at 3 (Rawle et al. 2012a). Additionally, A1758 is part of the the volume-limited high-$L_x$ LoCuSS subsample of 50 clusters and has *XMM* Newton imaging (see Martino et al. 2014 for further observational details). These observations were utilized to detect 39 new infalling galaxy groups surrounding 23 LoCuSS clusters, captured at their first encounter with the cluster environment (Haines et al. 2018). Furthermore, wide-field ( 1 deg diameter) optical spectroscopy with MMT/Hectospec was performed, as part of the Arizona Cluster Redshift Survey (ACReS; Haines et al. 2013). ACReS observations provide spectroscopic redshifts for 96 per cent of the sources detected at 24 µm with *Spitzer* down to 400 µJy. Archival SDSS and WISE photometry were added to the data pool. In particular, we used the AllWISE Source Catalog, reaching flux limits (at SNR 5) of 54, 71, and 730 µJy for 3.4, 4.6, and 12 µm, respectively.[1]

[1]http://wise2.ipac.caltech.edu/docs/release/allwise/expsup/sec2_1.html

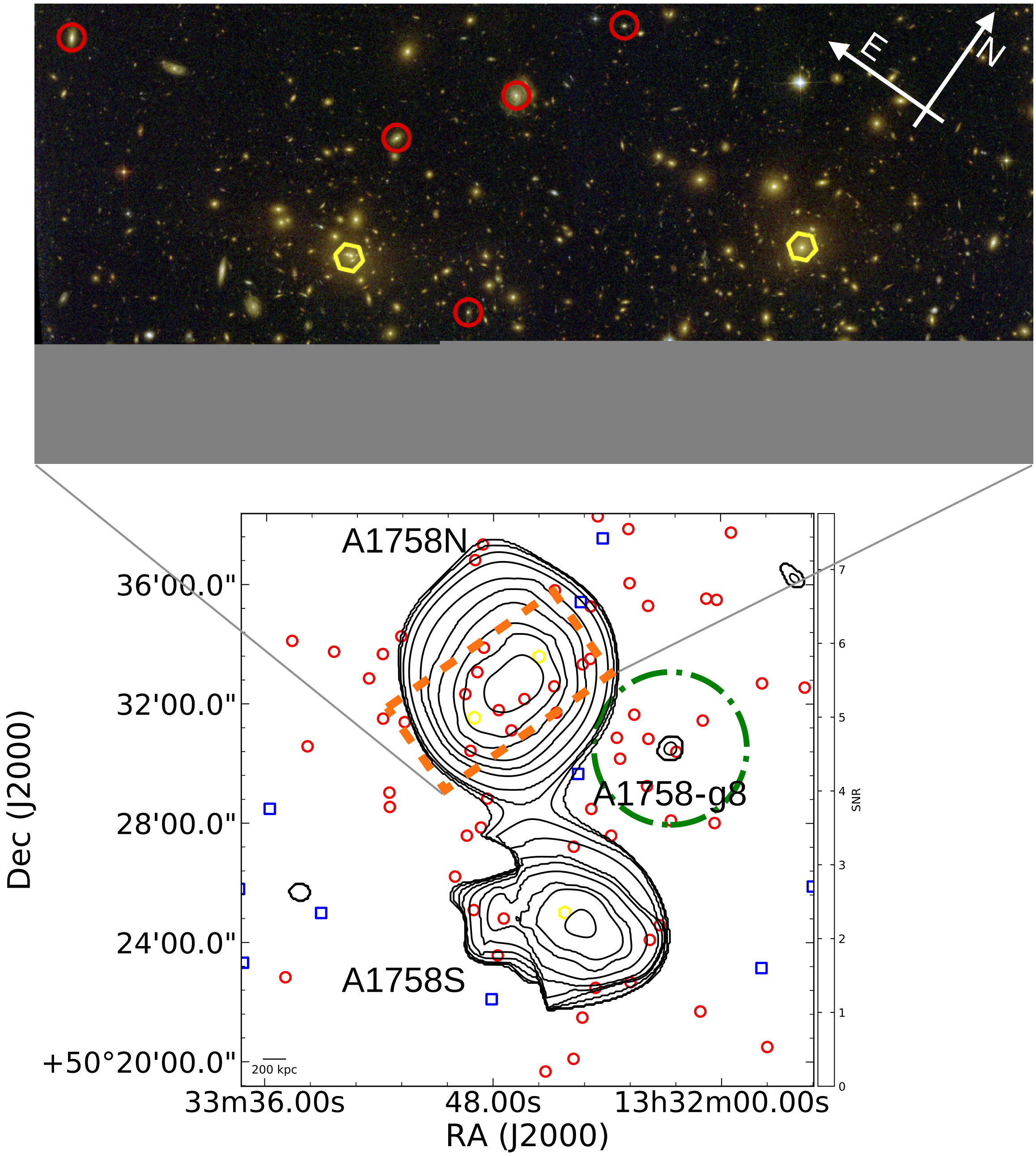


**Figure 1.** The merging cluster A1758. Top panel: zoom-in mosaic of A1758N observed with *HST* ACS in F435W, F606W and F814W filters from the RELICS survey (Coe et al. 2019). Bottom panel: the underlying map in shades of black shows the surface mass density signal-to-noise ratio based on the weak-lensing analysis of Okabe & Smith (2016), see end of Section 3. The black contours trace the extended X-ray emission measured with *XMM Newton*, detected above a $4\sigma$ threshold in the wavelet analysis (Haines et al. 2018), and are logarithmically spaced between $6.3 \times 10^{-7}$ and $3.9 \times 10^{-5}$ counts $s^{-1}$. Star-forming cluster and field galaxies are plotted as the red circles and the blue squares, respectively. The yellow hexagons mark the brightest galaxy position of the three cluster subclumps, referred to as NW, NE, and S according to their coordinates. The X-ray contours encompassed by the green dot–dashed circle (with radius equal to $r_{200}$) correspond to the X-ray group A1758-g8 discovered in Haines et al. (2018).

In this work, we focus on star-forming galaxies, both as cluster members and field galaxies. The sample of coeval field galaxies is included as a benchmark to allow the study of environmental effects on star formation. In particular, we consider those spectroscopically confirmed cluster member galaxies that are detected at 24 μm and also lie within the *Herschel* PACS footprint. Field galaxies are selected from observations of five additional clusters from the LoCuSS survey at $z < 0.3$, which were observed with *Herschel* PACS and SPIRE instruments in the exact same way as A1758, which is covering the same sized fields (25 arcmin × 25 arcmin) to the same depths in all five far-IR bands. From these data, we select field star-forming galaxies within the redshift range $0.23 < z < 0.30$ after excluding those galaxies within 4000 km $s^{-1}$ of the mean redshift of cluster members (Haines et al. 2013).